Water Resour Manage (2013) 27:1013–1035
DOI 10.1007/s11269-012-0117-y

Developing Novel Approaches to Tracking Domestic Water Demand Under Uncertainty—A Reflection on the "Up Scaling" of Social Science Approaches in the United Kingdom

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Received: 13 December 2011 / Accepted: 20 July 2012 /
Published online: 4 August 2012

Abstract Climate change, socio-demographic change and changing patterns of ordinary consumption are creating new and unpredictable pressures on urban water resources in the UK. While demand management is currently offered as a first option for managing supply/demand deficit, the uncertainties around demand and its' potential trajectories are problematic for water resources research, planning and policy. In this article we review the ways in which particular branches of social science come together to offer a model of 'distributed demand' that helps explain these current and future uncertainties. We also identify potential strategies for tracking where the drivers of change for demand may lie. Rather than suggest an alternative 'demand forecasting' technique, we propose methodological approaches that 'stretch out' and 'scale up' proxy measures of demand to inform water resources planning and policy. These proxy measurements could act as 'indictors of change' to water demand at a population level that could then be used to inform research and policy strategies. We conclude by arguing for the need to recognise the co-production of demand futures and supply trajectories.

Keywords Water demand · Practices · Socio-technical systems · Climate change · UK

1 Introduction

Climate change, socio-demographic change, and changing patterns of ordinary consumption are creating new and unpredictable challenges for the UK water sector (see DEFRA 2011, for a comprehensive review of these studies). The south (S) and south east (SE) of England are particularly vulnerable to extreme events due to climate change (floods, droughts, heat waves) and increasing levels of water demand (Arnell 1998); at the time of writing (first

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quarter 2012) many areas in the SE of England were classified in drought, following successive dry winters and spring (Environment Agency 2012). In the last two decades, there has been a large shift to demand side management of potable water for household and other uses in the UK (McDonald 2007). Although globally the demand for agricultural and industrial water is considered to be one of the most significant, reduced industry and mining activity in the UK has meant that non-potable water demand has actually decreased over time (McDonald 2007). Domestic water and related consumption of potable water is therefore one of the most significant concerns for the UK.

As such, demand management at the household level is increasingly viewed as a robust, low regret adaptation option in the face of climatic change (c.f., United Nations 2006; Gleick 2002), and a key component of water management strategies in the UK (Environment Agency 2009a, b). It is seen that there is little or nothing to be lost economically, environmentally and in terms of infrastructure design from seeking to limit the quantity of water that households use (Environment Act 1995 chapter 25 1995). Despite this increasing focus on household water use reductions, policy and regulatory frameworks are such that under current 'service level agreements' water companies must maintain a constant supply of water to domestic customers for indoor use, maintain a minimum water pressure, and establish an acceptable frequency of hosepipe bans as a balance of cost to the consumer and company investment. Large scale infrastructural supply solutions are still being considered where such investments are proven to be necessary to balance this supply/demand deficit in line with customer expectations[1] (Environment Agency 2010). As McDonald et al (2011) highlight "the industry is investing in an infrastructure that will supply the water demanded on effectively all occasions" (p 68).

Research on the future(s) of UK water demand have tended to be dominated by approaches that attempt to gain more precision and simplicity in demand forecasting by modelling the micro-components of demand and from there estimating demand patterns at the population level (Herrington 1998; Herrington 1996). In other countries such as Australia this approach is referred to as water end-use studies (Giurco et al. 2010; Willis et al. 2011). Micro-component analysis models water flow at specific 'micro' outputs (e.g., kitchen sinks, showers, toilets, garden taps) in individual homes, and relates this to a range of contextual information from demographics to weather data. Two calculations have come to dominate demand research and forecasting; the first is to estimate domestic demand based on micro-components and what is known as the OVF (ownership—O; volume used per usage—V; frequency of use—F) of technologies (Herrington 1996). The second is the use of information such as population change, socio-economic status, rateable value, household type, and compositions of households such as age, partnership status and number of children as characteristics to predict demand (Downing et al. 2003; McDonald et al. 2011; Memon and Butler 2006).

The micro-components approach moves to a group level analysis through the imputation of demand for similar kinds of households. It then examines what the impact of shifts in consumption of particular micro-components might be, and what effects group characteristics, weather variability and other variables such as bank holidays may have. Parker & Wilby (this issue) are some of the first in the UK to directly consider the interactions between micro-component data and weather (precipitation and temperature) providing some interesting reflections on the weather variability of certain end-uses which may assist in locating potential demand based change in the context of climate change. Although micro-component based forecasting is useful in establishing an averaged understanding of demand,

[1] with 'deficit' defined as existing supply not able to meet current and/or projected demand

with little linking of this data to detailed behavioural data, it struggles to fully capture the range of behaviours associated with those end-use volumes in the 'real world' (McDonald et al. 2011). Previous research on the assumptions underpinning this approach has shown that even for households using an amount of water similarly close to the statistically average pcc (per capita consumption) there is significant variation in the sites of micro-component consumption (Medd and Shove 2006). The industry focus on reducing statistically average levels of pcc is misleading in terms of the diversity and variability of actual domestic water consumption for equally diverse demographics (Medd and Shove 2006), and the potential for these patterns to shift under uncertain futures.

In this article we propose an alternative approach to micro-component analysis which adds value to these dominant approaches. Current policy and research frameworks, even when prioritising the twin track of demand management in combination with supply, consider demand as a figure that can be extrapolated and expanded according to population projections (Memon and Butler 2006). The perspective of demand as something that simply draws on supply, and that the supply system will expand to meet the water demanded on all occasions sits in opposition to literatures which highlight the way supply and demand are co-produced; that is, that supply development sets an assumed trajectory of consumption patterns and volumes (Taylor and Trentmann 2011; Moss 2000; Shove 2003; Van Vilet et al. 2005). In this article we draw on the latest social science debates to suggest two significant conceptual shifts that are required to get beyond the current impasse.

In an attempt to start to more systematically address these unknowns, this article extends previous work on alternative conceptualizations of demand management in the UK that attempted to reveal the assumptions about demand in existing systems of water practice and provision (Chappells et al. 2011; Medd and Chappells 2007, 2008; Medd and Shove 2006; Taylor et al. 2008). It achieves this by moving away from the focus on water resources and individual behavior, and focusing attention on factors which, despite prominence in research on water resources planning and demand intervention, fail to account for the gap between people's attitudes and their behaviors. This gap is consistently observed in demand management and other environmental settings (Russell and Fielding 2010). Instead, the theory and research presented in this article attempts to understand the gap between environmental/water attitudes and actual practices of consumers by moving towards an appreciation of the way that every day practices create and sustain change, and the way that these practices are related to technological, infrastructural and cultural development by 'letting go of water' and explicitly considering the 'distribution of demand'.

First, we suggest there is too much water in water demand research! Instead, we propose that the value of water, and drivers of water demand, lie in the value of the services that water enables for the domestic consumer. The service level agreements set a constant supply of water to peoples' homes which enables this range of services. Cleanliness, comfort, leisure, convenience, health and psychological wellbeing are all services that are provided through water consumption. Second, we suggest there is too much emphasis on the individual consumer and propose instead an approach focused on distributed demand, in which demand is located and constituted through multiple distributed relations between everyday consumers, the socio-technical systems of provision and the emerging conventions of 'normal' consumption. Third, we introduce a range of potential methodologies that could be used in water research, water policy and the water industry that focuses on proxies of water use consumption based on the perspectives outlines in the first half of the paper.

2 The Importance of Letting Go of Water

From a social science perspective, a core problematic of understanding water demand is the difficulty of making visible the inconspicuous, taken for granted water consumption and waste water production embedded in the use of infrastructures and technologies in the modern home, and the connections of this demand to current and shifting urban infrastructure (Kaika and Swyngedouw 2000; Sofoulis 2005; Allon and Sofoulis 2006; Shove 2003; Hand et al. 2005; Kaika 2004; Geels 2005). This inconspicuous consumption becomes particularly concerning for a sector seeking to anticipate the challenges of climatic change in combination with other population, cultural and technological changes. This process of estimation and forecasting is particularly difficult in the UK since the majority of domestic water consumption is not measured (i.e., metered), and therefore the true pattern(s) of total consumption of water in UK homes is not currently known (McDonald et al. 2011).

If there is a problem of establishing just what the baselines of domestic water consumption in the UK currently are, then our understanding the drivers of demand (from socio-economic dynamics, to variability of practices related to weather, to radical changes in behavior) that might influence future consumption patterns is even more important. Whilst a number of studies have forecast that water consumption will rise in the future (eg, Sharp et al. 2011; Environment Agency no date), others have shown that, although domestic demand measured over the long term has risen, there has been a decline in consumption in recent years which may be as a result of a wider take up of metering (McDonald et al. 2011). The metering hypothesis behind the fall in consumption is difficult to prove however, and it could be reflective of a fall in consumption of other material goods in the UK over the past 10 years (Goodall 2011).

While there have been some attempts to explore the impact of shifting socio-political scenarios of climate change in relation to the potential impact on micro-component usage (eg, Environment Agency no date), a wider sense of connecting such changes to the meanings of water in a more sociological sense (e.g, Strang 2004) has been relatively neglected. This lack of integration of the water industry with the broadest set of social science disciplines (sociology, geography, history, philosophy) is a large gap in understanding in the area of climate change and adaptation (Shove 2010). This is significant as despite a plethora of research on water use from psychological and economic related disciplines it is still relatively unknown whether people's attitudes towards the environment and water, people's intentions to conserve water or install water efficient devices lead to actual sustained water conservation and savings (see Russell and Fielding 2010, for a comprehensive review of these studies). In fact, it is well known that attitudes, intentions and self reported consumption are not predictive of actual water consumption (Hamilton 1985; de Oliver 1999) and that most water used in the home is relatively inelastic to price (Schleich and Hillenbrand 2009; Arbués et al. 2003; Arbues et al. 2010). This is known in the literature as the attitude-behavior or value-action gap (Gregory and Di Leo 2003).

Therefore, despite considerable national and international research there is still a dearth of understanding about what people's water use practices actually are; how these practices relate to water consumption; and how the maintenance or growth of water demand might be related to changes in these practices over time. Moving beyond a focus on 'water', sociological research has gone some way towards suggesting alternative conceptualizations of demand as constituted through the routines and habits of everyday practice as well as the systems of provision that make water consumption in its multiple forms possible (Medd and Chappells 2008; Medd and Shove 2006; Shove 2003; Sofoulis 2005; Strengers 2011; Geels 2005). These approaches focus on a deeper understanding of how people use water, what they do when they are using it, why they use it and when they use it. Such qualitative work has been powerful in the messages about the complexities of water use it has imparted to the UK water industry and in shaping international research agendas. However, the conceptual and theoretical insights from this research are yet to be translated into methodological formats that could be more meaningfully and pragmatically integrated into current practice of those more directly involved with managing water resources. Following on from these theoretical traditions the following section on distributed demand explores how this notion of demand expands the conceptual and methodological basis of these traditions in a way that may have more applicability for the water industry.

3 Distributed Demand

The assumptions that limit the micro-component modelling approach and other dominant water management perspectives is that the problem of demand is framed within units of analyses based on the individual user, the static household and water as a resource. An alternative perspective is interrogating the services that water provides, and locating the unit of analysis as the practices that underpin this service provision in peoples' everyday life. There are some writers on UK water management who are starting to move towards an understanding of demand management that focuses on both the technical measures and the behavioural changes required to address future demand (eg, McDonald et al. 2011; Bell et al. 2011). We would push this further and suggest that when the unit of analysis is scaled beyond the individual and beyond water per se, significantly insightful reflections emerge regarding the values of, and attitudes to, the services that water provides, the nature of complex everyday routines, and how systems of provision shape demand.

Pushing this perspective of water demand as both behavioural and infrastructural further, demand should be seen as multiplicity—it is not one thing. Historians and social/cultural theory shows us how demand has formed, emerged, and come into being through a complex process of public health agendas, changing agendas around consumer rights, emerging infrastructures of water provision and waste. These approaches argue how these public infrastructures are linked to the development of internal space in homes, a process which enabled an emerging set of routines, technologies and habits around personal and family care (bathing, showering, cooking) (Trentmann and Taylor 2007, 2006; Shove 2003; Hand et al. 2005). Household demand cannot be seen as simply located within an individual or household, as it is emergent from multiple human-natural-technological relations. In this sense, understanding demand as a socio-technical-natural 'assemblage', means understanding its creation, maintenance and transition as distributed throughout an interconnected supply and demand system.

We can see the significance of a distributed approach to demand by following the relations that constitute the practice of showering. Indeed showering presents an interesting paradox: often cited as a way to save water instead of taking a bath, new showering technologies and the recruitment of people to showering as a practice has pushed the consumption of water beyond that originally consumed through the practice of baths (Critchley and Phipps 2007). Accounting for this surge of showering demand as situated in the decision making behaviour of the individual consumer and measured through micro-component flows would be limited. A more distributed approach to demand suggests the need to look further afield to account for the development of showering (following Hand et al. 2005).

First, there are innovations in plumbing, heating and power that have enabled the movement of bathing from communal bathing houses to individual homes and the new variations of technology within such homes (notably power showers). Second, and in addition to these technological innovations, Hand et al (2005) describe changes in expectations and values of the body and self, in particular the emergence of multiple representations of individual cleanliness, freshness and fitness such that showering functions in multiple ways to 'get clean', 'wake up', 'freshen up', 'relax' and so on. And finally, in addition to the technologies and infrastructures and cultural representations of bodies, demand for showering is distributed, through the temporal organization and the routines of everyday life in which showering becomes associated with speed and convenience in increasingly pressured lives. We need to look beyond individual components or elements to see the distribution of demand across the emergent arrangement of showering as a whole, including the institutions and regulatory relationships that ensure water (and energy) is supplied consistently and of the right quality and pressure.

Household water demand, in other words, is distributed across a complex system of industrial systems, actors and social practices including: individual bodies and what they do, how they are perceived and presented; within households and between households; between other public spaces like parks, gyms, schools and places of recreation; places of business; within water supply infrastructures; between water supply infrastructures and wastewater systems; between sewerage treatment works and the pipes that either dispel that water back into the environment or intentionally pump it back into drinking water supplies; in the designers and manufacturers of our desired bathrooms and laundry technologies and fittings; the beauty care and products industry; the designers and manufacturers, purchasers and buyers for DIY stores; garden designers and outdoor lifestyle promoters; the different business agendas of water companies in a regulated water industry; the policies, regulations and frameworks of government departments. The influences on this distributed demand are both material and conceptual—demand is distributed across physical infrastructure and physical stuff (the things we consume, as well as what we do with those things), as well as distributed in social and cultural images, services that water provides (family care, lifestyle, health, comfort), and policies and regulations.

Given this perspective, since demand is constituted through multiple distributed relations, we can begin to see how demand shifts as different relations come into play, how these different elements become significant and how through these elements different and new combinations form. This leads into a question about how, if we start to change different elements of those relations, demand may start to shift in different ways and at different scales. The difficulty then becomes how to capture this understanding of demand as we have presented through this social science perspective in a way that captures complexity and yet provides some tangible methodologies to reflect changes as they are occurring (both with and without intervention). How do we stretch (broaden) and scale up these relatively small 'n=' examples in a way that illustrates the possibilities of thinking about, modelling, and monitoring future demand?

4 Adventuresome Research: Scaling up Methods for 'Distributed Demand' and 'Disappearing Water'

As we have noted, much of the previous research from this social science perspective has been qualitative, aimed at developing detailed expositions of the case to make explicit the analytic value of adopting these orientations. However, this does not seem sufficient for the purposes of large scale water resource management where even an aggregation of multiple detailed cases can still only provide a richer rather than actionable picture. In an attempt to scale up these orientations towards the practical needs of water resource managers and to operationalize the research at the population level, this article reflects the initial development of quantitative methodologies that scale the fundamental understandings of this perspective and levers existing investments in large scale household survey datasets to do so. As such it is part of growing response to a call to arms for social science to scale its data to fit with data in various types of natural resource management (Liverman and Cuesta 2008). This article reflects one attempt to translate the actual complexity of demand as we see it within a research language and methodologies more readily understood by other disciplines and crucially, by public policy makers and commercial strategists. A number of embryonic methodologies for monitoring social change related to water demand are developed. The approaches presented potentially increase the adaptability of water resource systems by monitoring change to societal level water use practices over time at little cost (except the knowledge and the analytic capability) to water resource managers and policy makers.

Of course, some authors (eg, Sharp et al. 2011; Strengers 2011) caution that research approaches to water demand management which rely on prediction and forecasting cannot be reasonably integrated with approaches that challenge the status quo of the system such as the perspective we have identified in the previous sections. Sharp et al (2011) using UK water management examples referred to the incompatibility of approaches that challenge the status quo with approaches and methodologies that are deeply embedded in existing policy and practical processes for water demand management such as the micro-components approach, or forecasting approaches used by water companies (Sharp et al. 2011). However, using an adventuresome approach to pluralistic forms of research inquiry (eg, Kelly 2003) we argue that we can develop methodological approaches to monitor and enhance the adaptive capacity of a water resource while still challenging the status quo and maintaining theoretical and philosophical integrity.

Our argument therefore is that we can use methodologies that have traditionally been associated with positivist science in an adventurous way (Kelly 2003) to scale up social research and use these methodologies to reframe scientific and policy questions and guidelines in a useful way. This is significant, as Sharp et al. (2011) reflect: “Without concepts and models for assessing future human water needs, or indeed, the needs of the environment, we would find the processes of planning and developing our world impossible, as each decision would require that we referred back to the fundamentals of the case” (Sharp et al. 2011, p. 512–513). Seeing water demand as distributed in space and time we offer a set of methodologies to monitor changes to the social environment, which reflects a similar approach to the use of ecological and environmental monitoring to capture shifts within ecological systems in the face of environmental and climatic change (Spellerberg 2005; Parr et al. 2003; Burt 2003).

4.1 Barometers of Change: Establishing Key Social Data Monitoring of Demand Based Change

Monitoring can be defined as the systematic collection of data in a standardized way across a period of time. Indicators of change do not necessarily reflect a complete picture of the change, but may act as focus points providing relevant information to policy makers and publics (Land 1971). Rather than considering the approach under discussion as a set of fixed social indicators it is helpful to consider the following methodologies through a metaphor of *barometers of change* (Sarason 1996). What we are considering here are barometers indicating particular types of social, institutional and individual change that may reflect changes to underlying patterns of water demand now and into the future. From this point informed decisions could be made about investments for future research priorities where there is an identified lack of understanding, decisions to be made about points and scales of intervention, and the impacts of infrastructural development.

Much of the research focused on social indicators within climate change adaptation literature focus on issues of vulnerability, sensitivity and resilience to change (Yohe and Tol 2002; Adger and Kelly 1999; Adger et al. 2004; Cutter et al. 2003; Sherrieb et al. 2010; Hof 2011; UNESCO 2010). Despite a stated commitment to business practice that prioritises climate change adaptation, the indicators used to track changes in water demand in the UK are simply per capita consumption of households within a given area (eg, Greater London Authority et al. 2011) providing little detail of the issues of resiliency and vulnerability seen in climate change indicators. This UK water demand indicator is simply an aggregated number reflecting total water consumption per person in households, and reflects little of the nuanced technological, infrastructural or behaviour based changes that lead to this increase in abstraction for household use or the perceived ‘vulnerability’ embedded in the development of particular infrastructures.

Given our perspective, the establishment of a range of methodologies that reflect changes and developments in key social data that may enable us to access in-depth information about key changes to water consumption based on the different areas of the distributed demand system is crucial. Monitoring a range of representative potential future realities would mean that as real time information becomes apparent different decision making methods could be implemented. This is in line with the monitoring of key physical data in order to inform decision making strategies about resources and infrastructure. The approach that we are suggesting would allow the development of monitoring methodologies that capture the progression towards and into different trajectories of change. Spontaneous alterations in trajectories may have as much an influence on future demand as planned for trajectories (Shove and Walker 2007); therefore, this approach could significantly enhance the adaptive capacity of the system.

Based on the discussion in the previous sections, it is clear that firstly in the development of these indicators *we need to let go of water*. It is by getting rid of water that the lifestyle amenity value of water providing different types of services is recognized. Cleanliness, comfort, leisure, convenience, health and psychological wellbeing are all services that are provided through water consumption. From here, if we are to think of household level demand, we need to think about what services water provides, to whom and what else is involved in the provision of these services. In the remainder of the paper we develop these ideas using two approaches which both provide indictors or proxies for elements in the distributed demand system by explicitly letting go of water. In the first example we focus on the consumption of material goods and services as measured by household expenditure data as proxies for water-using practices and in the second we explore the identification and analysis of water-using activities through individual level time-use data.

4.1.1 Charting Proxies of Consumption: The Importance of Material Elements (aka ‘Things’ and ‘Stuff’)

As we have argued, distributed demand is made up of the dynamic relationships between images of the activities that use water (e.g., a societal commitment to a particular concept of bodily and clothing cleanliness that requires daily or more frequent showering), the skills that it takes to do these activities (e.g., skills around personal hygiene and housekeeping), and the ‘stuff’ that is used in the achievement of these tasks (e.g., the washing machine, the shower gel, gardening practices, different types of washing powder, fabric softener). By tracking the different elements above and connecting material stuff with actual behaviors we argue that we can track *traces* (Bryne 2002) of the assemblages of distributed demand and their trajectories through time.

With the exception of some sociologists and designers (eg, Kuijer and de Jong 2009) in recent history the only material things that have been of significant interest in relation to water consumption, behavior and demand has been that of water efficient devices, and more recently in the UK the adoption of dumb and smart metering technology. However, when one looks closer into the routines and habits of everyday life there are many other things that are integral to the practices that shape water consumption that go beyond the usual suspects of toilets, shower heads, dishwashers, garden hose trigger guns and the other products given out in water efficiency packs. If we look to the practices that underpin micro-component data (practices of showering or laundry, gardening or doing the dishes etc) one can observe a plethora of 'objects', 'things', and 'stuff' that can be associated with water use.

A straightforward domestic self-audit might reveal different combinations of stuff you use when engaging with practices that use water: washing up liquid, cleaning solutions, laundry detergents/bleach/fabric softener, face wash, body wash, flannels, soap, shampoo, conditioner, tea pots, tea leaves and so on! Each item is implicated in a particular set of routines and habits, practices and performances that shape, and are shaped by, the diverse dynamics of water use in everyday life. Detailed information about the consumption of such products is readily available through regularly collected national expenditure datasets. These data sets are often collected by governments such as the UK's ongoing Living Costs and Food Survey (LC&FS; formerly the Expenditure and Food Survey [EFS[2]]), but commercial retailers also collect detailed information about the geographical spread of consumption practices and associated products (e.g., Tesco Club Card). As an example, the LC&FS is a government funded quarterly survey that collects a wide range of socio-demographic information as well as detailed household data about bills and expenditure for all people in a representative sample of UK households. The expenditure data is collected through a combination of survey and expenditure diary instruments and is coded into an exhaustive set of categories using the COICOP (classification of individual consumption by purpose) system which includes a wide range of relevant expenditures such as:

- laundry related items such as powders and detergents
- personal hygiene items such as soaps and shampoos
- food consumption items such as fresh vegetables, pasta and rice
- drinking related items such as tea, coffee, fruit squashes and bottled water
- gardening items such as seeds and plants

The details in these surveys can be incredibly fine-grained, for example, the category of 'vegetables' includes:

- c11521t margarine and other vegetable fats
- c11711t leaf and stem vegetables (fresh or chilled)

[2] Office for National Statistics and Department for Environment, Food and Rural Affairs, Living Costs and Food Survey, 2009 [computer file]. 2nd Edition. Colchester, Essex: UK Data Archive [distributor], May 2011. SN: 6655.

- c11731t vegetables grown for their fruit (fresh, chilled or frozen)
- c11751t dried vegetables
- c11761t other preserved or processed vegetables
- c11781t other tubers and products of tuber vegetables
- c12241t vegetable juices

In this section of the paper we use some of this data to get closer to integrating water use behavior within the complex social, technological and practical environments in which it is consumed. To do this we have pooled the expenditure data from the UK LC&FS for the years 2002 to 2009 for all 12,774 households who reported having a water meter (Table 1). Water expenditure is collected using a household survey and generally refers to the previous billing period. This is converted to weekly expenditure by the data collectors but, crucially, the data contains no precise indicator of the exact time period (i.e. season or month) to which the expenditure refers. As we discuss below this makes it difficult to examine any seasonal, quarterly or monthly effects.

Clearly the proportion of metered households in the yearly samples has increased over time (see Fig. 1), which support the broader agenda to expand metering in the English water industry (OFWAT 2009). We must also be aware that such households are not an unbiased sub-sample since metered households may be systematically different from unmetered households and that these differences are likely to become stronger over time (Herrington 2007). Bearing these caveats in mind, we then take their metered expenditure on water as a proxy for water demand once inflation and changes in water price over the period have been taken into account. To do this we first calibrated all expenditure data to 2005 prices using the ONS long term Consumer Price Index (CPI) series[3] and then calibrated the water expenditures by the water price CPI sub-component although as we note below this does not allow for price variation across water company areas to be factored out as a source of variation. Pooling the yearly surveys in this way provides a total sample size of 40,401 households for England where metering is present in all regions to at least some degree of whom only 12,774 were metered. By pooling the data we inevitably obscure the kinds of ‘households with meters’ effects mentioned by Herrington (ibid) and also obscure, in this analysis at least, any substantive changes to the relationships between practices, socio-demographics and water expenditure (use) over time. In some cases households paid for their water and sewerage separately and as we were unable to separate (metered) water expenditure from sewerage costs for the remainder we excluded these ‘separately billed’ households and assumed that sewerage costs would be adequately controlled through household tenure type and size. This restriction further reduced our available household survey sample size to 11,192.

We then take the household’s socio-demographic characteristics as indicative of particular water using practices. Thus for example a household in a detached house may use more water for gardening than a household in a terraced house or a flat; households with more persons may use more water but those with more children may use more (or less) due to different bathing and laundry practices. Further, and here we develop our analysis explicitly from our conceptual approach, we use the household’s expenditures on a range of other goods and services as proxy indicators for water use. Thus we suggest that expenditures on cleaning and bathing products, food and drink items, gardening items and so forth can all be used as

[3] http://www.statistics.gov.uk/statbase/TSDSeries1.asp

Table 1 Regional sample sizes (unweighted) over time for metered households, (LC&F Survey 2002–2010, authors' calculations)

Govt. Office Region	2002	2003	2004	2005	2006	2007	2008	2009	2010
North East	22	29	29	28	41	40	48	47	57
North West & Merseyside	104	127	141	100	159	138	166	148	186
Yorkshire and the Humber	125	153	149	112	169	179	171	167	187
East Midlands	123	167	134	109	198	135	151	156	191
West Midlands	142	123	112	108	105	114	112	148	129
Eastern	240	239	250	210	284	268	287	253	273
London	113	96	117	70	101	95	112	118	112
South East	202	216	249	197	291	277	288	266	278
South West	158	192	192	162	212	213	185	237	242
England Total	1229	1342	1373	1096	1560	1459	1520	1540	1655
All									12774

proxies for water-using practices within homes. As with the water expenditure these expenditures were converted to 2005 prices. Whilst it would be possible to build more complex models to tease out the significance and inter-relatedness of these practices, in this preliminary analysis we treat these factors as independent and accept that, for example, retaining accommodation type in the model may well suppress gardening practices effects.

In order to test the extent to which household socio-demographics, ownership of specific 'water appliances', income and our proxies for water-using practices contribute to overall water demand (as measured by metered water expenditure), we have then developed a simple linear regression approach (see Table 2). Not only did this model include a wide range of analytic variables of interest including equivalized household income[4] but it also included Government Office Region to control, albeit imperfectly, for regional diversity in water prices. Table 2 shows the variables included in the model clustered into blocks whilst Fig. 2 shows the contribution of each block to the overall explanatory power of the model (but not the magnitude of those effects).

As we might expect, the first block of variables (see Fig. 2) suggests some effects for Government Office Region, year and income. Looking more closely (see Table 2) there are regional differences in household water expenditure which are most likely to be indications of differential pricing with the notably higher expenditures in the South West (when all other factors are controlled) being a clear example. Our model suggests that here, metered customers were paying around £1.21 more per week compared to similar households in the North East. The coefficients for survey year, although intended here as controls also show a general decline in weekly water expenditure compared to 2002 and this effect becomes statistically significant from 2006 onwards as the trend increases in magnitude. Interestingly equivalized income was not a strong indicator of higher water expenditure but given the presence in the model of a number of other wealth indicators (see below) this is perhaps not surprising.

[4] Income was equivalized using the OECD modified weighting scheme to account for household size (Modified OECD Scale = net income before housing costs/ (1+0.5 * Number of Adults+0.2 * Number of dependent children<14))

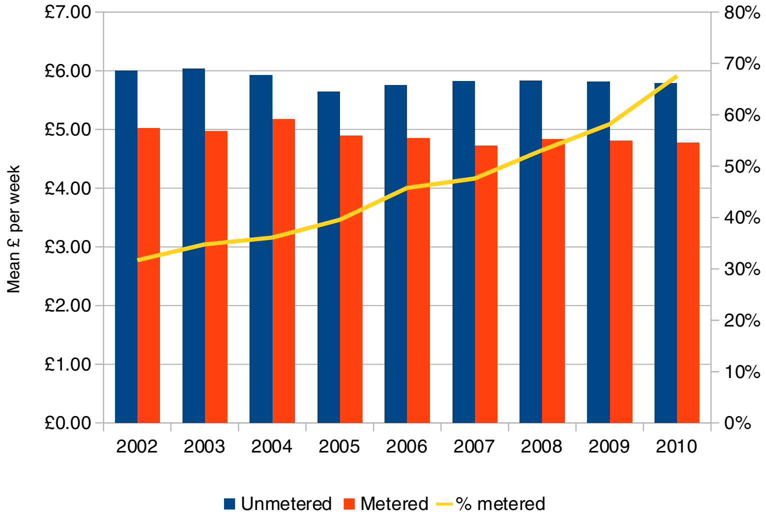

Fig. 1 Trends in household water expenditures for metered and unmetered households and overall metering rate, England (LC&F Survey 2002–2010, authors' calculations)

The next block of variables related to housing type make rather a larger contribution to the explanatory power of the model (larger change in r2) and from Table 2 we can see that this is largely driven by accommodation type and tenure. Thus living in anything other than a detached house is associated with lower weekly water consumption. Given that the number of rooms (house size) and number of persons (see below) is controlled in the model we interpret this as indicating differing water using practices by the kinds of people who tend to live in these kinds of house, not least perhaps the kind of gardening practices that might be associated with detached houses. Interestingly both social and other renters pay slightly more per week (c. £0.40) compared to those who own their own homes although the reasons for this are unclear.

As we can see from see Fig. 2, the block of variables that contributes most to the model (3) are those associated with wealth such as the number of cars, number of earners and employment status. In general the more cars and the more earners in the household, the less is spent per week on water and this is also true for households where the household response person is retired. In contrast and perhaps related to the effect for social and other renters, households with lower employment status (NS-SEC 3) spend more per week than those of higher employment status (NS-SEC 1) when income effects are taken into account (via block 1). Taking the next two blocks (4 & 5) together we can see that, as we would expect from previous studies (Arbues et al. 2010) increasing the number of people of nearly all ages has a significant positive effect on weekly metered water expenditure. In particular we note that whilst 2 people spend (use) more than 1 person (£1.20 more, not double) 3 people use only £1.59 more water per week confirming that such effects reduce in scale and the 'excess load' of multiple single person households. In addition there are also small but positive effects for those with a non-white household response person, potentially indicating cultural differences and small negative effects for households where there is a resident with a limiting long-term illness. Moving on to block 6 (water using appliances) we can see that as we might expect owning a dishwasher or a washing machine increases water use with the washing machine

Table 2 Results of linear regression model (OLS) predicting household water expenditure (Metered households only, LC&F Survey 2002–2010 all expenditures converted to 2005 prices

		b	95 % CI (lower)	95 % CI (upper)	Significance
Block 1	North West (North East)	0.824	1.046	0.602	***
	Yorkshire & The Humber	0.255	0.471	0.039	*
	East Midlands	0.409	0.634	0.185	***
	West Midlands	0.081	0.315	−0.153	
	East of England	0.734	0.949	0.518	***
	London	−0.057	0.213	−0.327	
	South East	0.124	0.346	−0.098	
	South West	1.209	1.450	0.968	***
	Year: 2003 (2002)	−0.076	0.137	−0.288	
	Year: 2004	0.106	0.331	−0.120	
	Year: 2005	−0.214	0.001	−0.429	
	Year: 2006	−0.301	−0.102	−0.499	**
	Year: 2007	−0.366	−0.157	−0.574	***
	Year: 2008	−0.235	−0.027	−0.444	*
	Year: 2009	−0.270	−0.067	−0.474	**
	Year: 2010	−0.342	−0.139	−0.544	***
	Equivalised income (BHC) decile 2 (1)	0.114	0.378	−0.151	
	Equivalised income (BHC) decile 3	0.002	0.221	−0.216	
	Equivalised income (BHC) decile 4	0.035	0.266	−0.195	
	Equivalised income (BHC) decile 5	−0.003	0.228	−0.234	
	Equivalised income (BHC) decile 6	−0.009	0.239	−0.257	
	Equivalised income (BHC) decile 7	0.044	0.286	−0.199	
	Equivalised income (BHC) decile 8	0.113	0.365	−0.139	
	Equivalised income (BHC) decile 9	0.053	0.309	−0.203	
	Equivalised income (BHC) decile 10	0.251	0.526	−0.025	
Block 2	Semi (Detached)	−0.202	−0.088	−0.317	***
	Terrace	−0.289	−0.148	−0.431	***
	Flat/maisonette	−0.235	−0.017	−0.454	*
	Other	−1.212	−0.537	−1.887	***
	2 rooms (1 room)	0.476	1.500	−0.549	
	3 rooms	0.686	1.665	−0.293	
	4 rooms	0.859	1.830	−0.112	
	5+ rooms	1.038	2.012	0.065	*
	Rent from council (Own)	0.210	0.439	−0.020	
	Social rent	0.455	0.660	0.250	***
	Private rent/other	0.403	0.608	0.198	***
Block 3	1 car (0)	−0.173	−0.035	−0.310	*
	2+ cars	−0.091	0.084	−0.267	
	1 earner (0 earners)	−0.363	−0.086	−0.640	*
	2 earners	−0.610	−0.238	−0.982	**
	3+ earners	−0.364	0.207	−0.936	
	HRP NS-SEC 2 (NS-SEC 1)	0.117	0.280	−0.046	

Table 2 (continued)

		b	95 % CI (lower)	95 % CI (upper)	Significance
	HRP NS-SEC 3	0.317	0.496	0.139	***
	HRP Inactive	0.099	0.401	−0.203	
	HRP Retired	−0.335	−0.006	−0.664	*
	HRP single parent (married/partnered)	−0.029	0.159	−0.216	
	HRP single person	0.764	1.204	0.324	***
	HRP other	0.127	0.441	−0.186	
Block 4	N Children <14	0.358	0.955	−0.239	
	N Children 14–16	0.625	1.301	−0.051	
	N single males 16–18	−0.167	0.380	−0.714	
	N single females 16–18	0.180	0.909	−0.549	
	N male adults <45	0.595	1.185	0.005	*
	N female adults <45	0.643	1.235	0.050	*
	N adults 45–60	0.800	1.394	0.206	**
	N adults 60–65	0.719	1.320	0.117	*
	N adults 65–70	0.795	1.406	0.184	*
	N adults 70+	0.648	1.262	0.034	*
	2 persons (1)	1.199	1.921	0.477	**
	3 persons	1.593	2.844	0.343	*
	4 persons	1.614	3.427	−0.199	
	5+ persons	2.192	4.751	−0.367	
Block 5	Limiting long term illness present	−0.358	−0.089	−0.628	**
	HRP 25–34 (16–24)	−0.119	0.223	−0.462	
	35–44	−0.174	0.179	−0.527	
	45–54	−0.348	0.091	−0.787	
	55–64	−0.587	−0.129	−1.045	*
	65–74	−0.698	−0.181	−1.215	**
	75+	−0.661	−0.122	−1.201	*
	Female HRP	0.042	0.154	−0.070	
	Non-white HRP	0.504	0.831	0.177	**
Block 6	Washing machine	0.433	0.641	0.225	***
	Dishwasher	0.299	0.405	0.194	***
Block 7	Potatoes	−0.004	0.060	−0.068	
	Leaf & stem vegetables	0.070	0.123	0.017	**
	Rice	0.070	0.169	−0.030	
	Pasta	−0.050	0.037	−0.138	
	Tea	0.104	0.169	0.039	**
	Coffee	0.014	0.059	−0.031	
	Fruit juices (incl squash)	0.069	0.106	0.033	***
	Vegetable juices	−0.164	0.000	−0.328	
	Mineral/spring water	0.107	0.203	0.011	*
	Soap/shower gel	0.084	0.147	0.020	**
	Laundry/Laundrettes	0.067	0.159	−0.025	
	Detergents/washing powder	0.066	0.103	0.029	***

Table 2 (continued)

		b	95 % CI (lower)	95 % CI (upper)	Significance
	Kitchen gloves/cloths	0.041	0.144	−0.061	
	Garden tools	0.002	0.017	−0.014	
	Lawn mowers	0.004	0.015	−0.006	
	Plants, flowers, seeds	0.003	0.008	−0.001	
Block 8	Spring (Winter)	−0.032	0.098	−0.161	
	Summer	−0.001	0.124	−0.127	
	Autumn	0.003	0.120	−0.115	
	Constant	1.025	2.344	−0.295	
	R2	0.266			
	RMSE	2.379			
	Log Likelihood	−25531.830			
	N	11192			

*$p<0.05$, **$p<0.01$, ***$p<0.005$, *HRP* household response person

having the largest effect even when the number of adults and children are suitably controlled elsewhere in the model (coefficients shown separately in Fig. 3 alongside block 7).

Skipping to block 8 (Season) we can see that our model does not detect any seasonal effects. On the one hand this is surprising as we would have expected a number of water-using practices to be associated with certain seasons but on the other the nature of this data means that it is very difficult to assign expenditure to specific months of water use and also households may respond to hot/dry weather by being more careful of water use, especially in drought conditions, and thus spending less. Finally however, we can see that block 7, the ‘practice proxies’ block of variables (coefficients shown separately in Fig. 3) make some contribution to the model (c.f. Fig. 2). Here we see no significant effect for the food proxies except for leaf and stem vegetables where for every extra £1.00 spent on these items, the

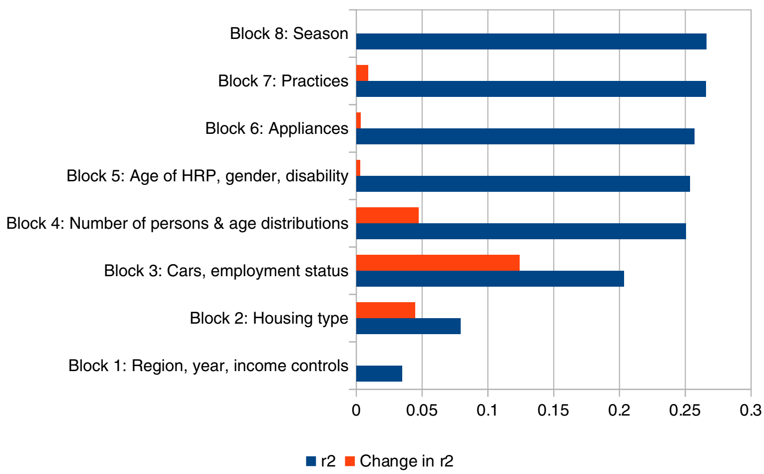

Fig. 2 Contribution of variable blocks to explanatory power of the linear regression model reported in Table 2

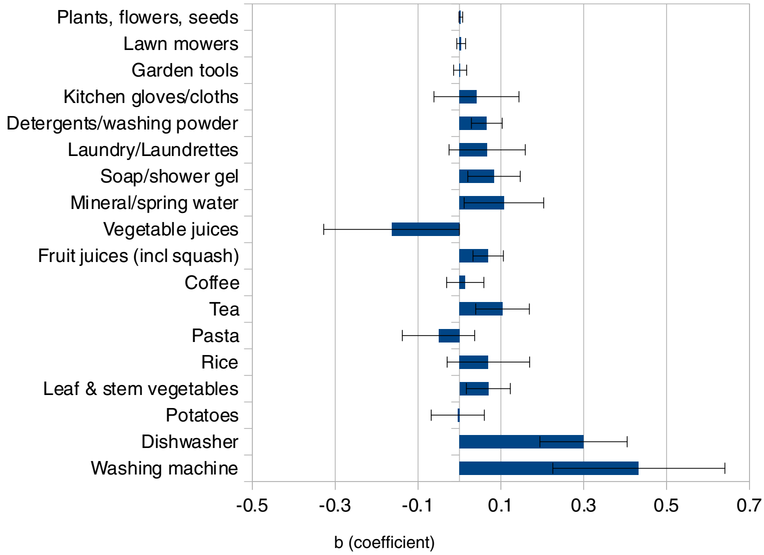

Fig. 3 Effects of water using appliances and practice proxies on water usage (metered households), Error bars are ±95 % confidence intervals for the estimates. Error bars straddling zero indicate non-significant effects at the 0.05 % level (extracted from linear regression model reported in Table 2)

household spends an extra £0.07 on water. However, the more a household spends on fruit juices (£0.07) and tea (£0.10) but not coffee, the more water they use but they tend to use less (−£0.16) for every £1.00 they spend on vegetable juices although the width of the confidence intervals suggests considerable heterogeneity in the size of this effect. Interestingly every extra £1.00 spent on mineral/spring water per week is also associated with an extra £0.11 spent on tap water per week and similar positive effects are seen for soap/shower gel and detergents/washing powder but not for any expenditures related to gardening.

Of course we must be careful not to over-interpret these preliminary results as they provide correlations (net effects) between different variables rather than definite proof of causal effects. In addition using water expenditure as a proxy for demand even for metered households is clearly imperfect as water price varies across company areas and (more rarely) service packages which are sources of variation that we cannot control with the data to hand. In addition expenditure on consumption items is only a loose proxy for practices as we are unable to distinguish between high expenditures which might reflect a few expensive purchases or which might reflect many cheaper purchases and there may well be very different practices associated with each; perhaps causing some of the large confidence intervals for the effects reported in Fig. 3.

However this approach to the 'stuff' embedded in water usage, using readily available large scale data sets, provides a way to think outside the box when it comes to understanding the distribution, and potential trajectories, of demand. These consumption traces reflect the opportunities for tracking and monitoring elements of practices that are associated with water demand; they reflect the opportunities that emerge methodologically when we start considering demand as distributed amongst multiple components of a system. By viewing demand as distributed throughout the complex elements of a system it opens up the opportunity for datasets such as this to become potential indicators or proxies of change at a societal level in relation to particular things. Whilst we cannot deduce causal relationships using this kind of analysis on these cross-sectional datasets, we can use them to open up sites of inquiry for more detailed analysis. For example using a dataset such as the UK's Living Costs and Food Survey could enable the analysis of year on year and indeed quarterly consumption and 'movement' of the stuff that could both driver of demand for water, the use of which will shape and also evolve as a result of changing practices.

Knowing how the consumption of the stuff that can be associated with water use shifts and changes over time might give us insight into how water demand might then shift. For example, consistently increased sales in outdoor lifestyle and gardening products across a number of years even in the absence of evidence for increased expenditure on water could indicate that there may be an increase in gardening water demand in a particular geographical area. This could lead to more targeted studies on shifting patterns of gardening and outdoor lifestyles (e.g., the emergence of 'garden rooms' (Chappells et al. 2011)) in certain locales, particularly if this observation is linked up to and supported by water company consumption data. Similarly an increase in showering products may show an increasing commitment to cleanliness and a potential increase in the recruitment of individuals into the practice of showering; similar patterns could be observed with laundry products and laundry. Indeed our current work is focusing on linking the expenditure data to local weather conditions to try to tease apart the relationships between water usages, water demand and local climatic experience. If successful could provide a nuanced model that could potentially be used to develop scenarios of future water demand based on empirically grounded relationships between changes in climate, consumption of water and other goods, and household demographics.

4.1.2 Time Traces—Linking Time Use and Practices

Besides spending money, the way people spend time is also crucial for understanding how and where they use water. Large scale time-use surveys are therefore valuable in understanding the potential elements of a demand system that may be shifting in a way that influences the consumption of water in the home. By following a similar 'proxy' approach, we suggest that time use patterns can also be used to develop more nuanced understandings of micro-component data and other such studies which look at detail at the end uses of water over time. As an example, national time use surveys (e.g. UK ONS 2005,[5] Multinational Time Use Survey—MTUS) capture a large amount of data on a large number of participants, are complex data sets, and like the expenditure surveys can capture historical cross-sectional, although rarely longitudinal, change. Such datasets capture changing daily rhythms and routines, and could be used to reflect how larger historical changes such as changes to employment policy or social norms also work to influence water using practices.

It makes sense therefore to consider and evaluate different sites, moments and forms of potential transformation whether prompted by changes in other related social arrangements or by specific forms of technological innovation or obsolescence. For example Fig. 4 reveals the patterns of a range of aggregated activities over the average weekday for respondents to the ONS' 2005 Time Use survey. In this case the survey provides data for each ten minute segment of the day starting at 04:00 for each of the 4,941 respondents who responded across Great Britain. We have selected the 3,565 who completed their diary on a weekday in order

[5] Office for National Statistics. Social Survey Division, ONS Omnibus Survey, Time Use Module, February, June, September and November 2005 [computer file]. Colchester, Essex: UK Data Archive [distributor], April 2007. SN: 5592.

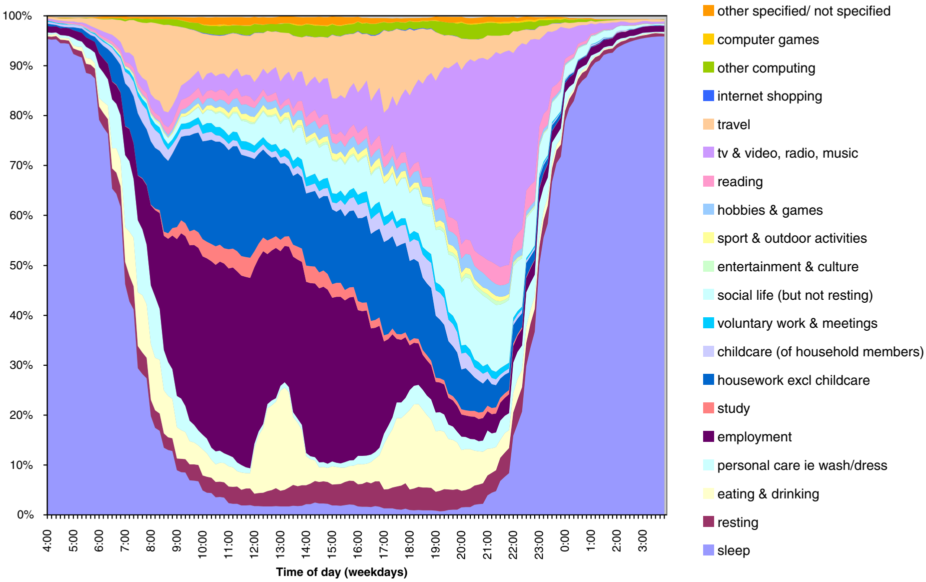

Fig. 4 Distribution of aggregated activity categories across the average weekday (ONS Time use 2005 survey, author's calculations, % of respondents reporting activity as 'primary activity')

to paint a rough picture of the flow of daily weekday activities. As we can see the 'average day' is dominated by sleep between 0:00 and 04:00; work between 08:00 and 18:00 and by media-based leisure from 19:00. Of course different sub-groups of the population will experience different profiles of activity but it is sufficient for our purposes to note that water-related practices such as personal care, housework, eating and drinking and child care show distinct non-random profiles. Were we to integrate data on location and mode of transport also available in this dataset then it should be clear that a powerful analysis of the flow of water within and between cities as populations undergo work, leisure and travel could be revealed.

As well as reflecting general patterns and trends which can be tracked over a day, weeks, years or decades, such 'time traces' also represent the interrelationships between different types of practices, and the time dedicated to different tasks in the home. This could be used to understand in more detail the habits, patterns and routines that shape daily consumption of water in people's homes (as evidenced for example through micro-component data). Further, qualitative research goes some way towards understanding the integrative and dispersed practices that shape those behaviors which are seen to specifically influence water demand. That is, rather than just seeing showering as a discrete activity, time use surveys such as this facilitate an approach to showering as it is connected, and disconnected, with different pre-cursors and successors as well as different pressures that make up people's daily time schedules. For example, how does showering relate to and fit into peoples' use of public transport, their exercise routines, or their work and leisure schedules? Such sequence modeling is seeing increasing attention in the time use and wider sociological methods literature (Lesnard 2010).

Understanding the changes to lifestyle, work, transport and other practices inside and outside of the home provides extra understanding to changing trajectories of water demand (peak and overall). For example, changes in information and communication technology, increasing the availability and acceptability of more flexible patterns of work (such as working from home) could influence the time-geography of everyday life, and impact the ‘how’, the ‘when’, and the ‘how much’ of water consumption in the home and other spaces (e.g., Krantz 2006). Other developments are also likely to influence the routines and habits of water using practices in the home. Where and how a burgeoning population of elderly people spend their time is one such issue (Barrett and Wallace 2009); as is the uncertainty embedded in demographic change such as fertility and mobility (Boden 2011). Datasets that reflect these ‘time traces’ could provide some interesting insights about shifts to water using practices and how this relates to other aspects of peoples lifestyles (and societal/demographic trends). That is, tracking the way that certain practices shift temporally and spatially may turn out to be a different way of quantitatively modeling the changes in water consumption practices over time.

4.1.3 Future Research: Spotting and Tracking Practices

We have argued that current approaches to demand management generally miss the detailed richness and heterogeneity of practices that use water, if they consider them at all other than indirectly through household sizes and age profiles. The examples and preliminary analyses we have discussed above have shown the value in considering practices explicitly in any explanatory model of water demand and this leads us to consider the nature of suitable future research. Clearly there needs to be considerable effort devoted to identifying and describing practices including the analysis of their distributions across different kinds of households, work and leisure spaces, and cultural boundaries. This argues for an explicitly practice-based approach to large scale water-survey work. The project team have implemented such an approach in more recent work which has collected data on reported practices linking this to observed water data sourced from water company billing systems for metered households, and the analysis of which is nearly complete (Anderson et al. 2012). This is already enabling us to develop broader understandings of the routinization and reflexivity of certain water use practices which are being evaluated and fleshed out through a phase of qualitative work (expert workshops, interviews and focus groups) which in turn, is already leading to new avenues for future qualitative and quantitative research and analysis on future trajectories of water demand.

However, we would also argue that current approaches fail to reflect on the ways in which practices change in terms of normative expectations but also in terms of seasonal or climatic responses. For instance, it is possible that hotter summers, combined with current societal standards of freshness and an aversion to sweat, might lead to an increase in water used for laundry and showering in the UK. The reverse might be true as populations get used to a normalized hotter UK environ. Equally, some sites of consumption, and some water-using practices—like garden watering—might be relatively rigidly defined in terms of timing and frequency, but flexible with respect to the quality of water involved (Russell and Hampton 2006; Nancarrow et al. 2008; Dolnicar et al. 2010; Hurlimann and Dolnicar 2010; Hurlimann and McKay 2007; Hurlimann and McKay 2006). Changing household infrastructures and watering the garden with fit-for-purpose water recycled from within the home, or captured storm water may become a real (necessity and) possibility (Nancarrow et al. 2008). Gardening practices therefore could be a site of transition for some households, and with respect to some aspects of water use (Browne et al. 2007; MacDonald et al. 2010; Hitchings 2007; Chappells et al. 2011). Understanding the diversity of potential transition points in the practices of different households is vital if we are to develop an empirically grounded approach to modeling future scenarios of water demand under varying climatic and socio-cultural conditions.

5 Scaling Up Practice: Conclusion

It has been observed that "Patterns of demand are quite literally *traces* of the complex of practices through which water is actually consumed" (Medd and Shove 2006, p. 40). At a minimum this suggests paying close attention to the ways in which peoples' ability to adapt and respond to climate change is organized, structured and constrained by existing socio-technical-natural assemblages of (what we have described as) distributed demand, including the wide array of infrastructures and household technologies, cultural conventions of what is 'normal', and the habits and routines of everyday life. While some within the cultural turn of water management would caution the use of methodologies that can be scaled to more easily integrate with existing management approaches (Sharp et al. 2011), we feel that with appropriate methodological pluralism (Kelly 2003) a critical approach can be maintained while still providing reflections of relevance to science and policy.

Establishing broad indicators of social change reflecting distributed demand could increase the adaptive capacity of the water resource system in the UK as a whole, and provide an interesting template for other countries and regions such as the EU. It would provide information as to significant social trends associated with water use and water demand over time, and provide insights into the changes to water demand both with and without intervention. This approach could reveal significant new adaptation pressure points as well as reducing the path dependency of large infrastructural decisions (Barnett and O'Neill 2010; Moss 2000; Moss 2008; Vairavamoorthy et al. 2011). As suggested these barometers of social change are not necessarily linked to assessments of vulnerability but should be initiated with the express purpose of enhancing the adaptive capacity of the UK water resource system to socio-cultural and climatic changes. This approach could enable decisions makers in business and government to understand the multiple locations at which such change occurs, and from here make informed decisions about investment for research and knowledge generation to inform policy, planning, and systems based intervention.

The challenge for water demand management and forecasting under conditions of uncertainty due to climate change is to understand how water using practices, technologies and conventions might themselves evolve, and the extent to which existing approaches to infrastructure management and expansion may enable, reinforce or disrupt such changes. It is difficult to predict what new water-using technologies and practices might emerge, or how current water-consuming devices and routines might disappear or be substituted by arrangements and ways of doing things that require less, or perhaps no water (Ben-Haim 2006; Shove and Walker 2007). As with other forms of 'socio-technological forecasting' our ability to influence the combined trajectories of people's water using practices and to offer scenarios of what this change will look like may be limited (Anderson and Stoneman 2009). Gram-Hanssen puts it this way, people change their routines all the time but "not as a result of concern for the environment or the result of campaigns… it is rather due to changes in the social organization of everyday life combined with the introduction of new technologies" (Gram-Hanssen 2008, p. 1181). Recent empirical studies of attempts at futurology suggest that, amongst other problems, major reasons for failure have been an over-emphasis on technological determinism, a poor understanding of social trends and change, and finally, the over-reliance on a linear progression model of change (Geels and Smit 2000; Bouwman and Van Der Dun 2007). Although the contours of future water-using practices, and the extent of variation within these, are necessarily uncertain in this paper we have identified nuanced, detailed and distinctly non-linear ways to capture insights and clues about this future as it emerges.

Acknowledgments This research was funded by the Engineering and Physical Sciences Research Council (EPSRC) ARCC-Water project (Adaptation and Resilience in a Changing Climate), and the Economic and Social Research Council (ESRC) Sustainable Practices Research Group (SPRG) 'Patterns of Water' project.

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